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(DES)INVESTMENTS IN THE  
DAIRY COW STOCK**

**J.H.J. Roemen**

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# A DECISION RULE FOR THE (DES)INVESTMENTS IN THE DAIRY COW STOCK

J.H.J. Roemen

## Abstract

In this paper we present (a simplified version of) an alpha-numerically specified model for the development of the national milk supply in the long run. From this model we derive reaction equations for the optimal level of the (des)investments in the dairy cow stock. These relations can be used as a starting point for e.g. the estimation of the long run elasticity of the milk supply with respect to the milk price.

## 1. Introduction

The national milk supply is equal to the product of the average milk production per cow and the size of the national dairy cow stock. In normal circumstances the size of this stock is approximately constant in the short run, that is, within one year, hence the main possibility in the short run for modifying the national supply in response to a changing milk price is the yield per cow. In the long run, however, the level of supply can also be changed by altering the size of the stock. This can be effected by putting in calf (inseminating) more (less) heifers this year than will be needed as replacements in the following year, by the level of culling or finally by a combination of these possibilities.

In this paper we present a simplified model of the determinants of the milk supply development in the long run. Because the individual farmer decides upon (changes in) this supply, we consider the underlying decision process at the farm as an obvious point of departure. For this farm we formulate a dynamic, alpha-numerically specified model of milk supply. From this model we derive decision rules for the optimal level of the

(des)investments in the dairy cow stock. The resulting reaction equations specify these levels as a function of, among other things, present and expected prices. So these relations provide a starting point for e.g. the estimation of the long run elasticity of the milk supply with respect to the milk price, using farm data. If we assume that the same type of model as the one considered here holds for all firms in the sector, the requirements for consistent estimation are satisfied, and estimation using sector data is also allowed.

## 2. The problem

To get an idea of the considerations which determine the size and age composition of the dairy cow stock, and so the levels of in- and outflow, we consider an individual dairy farm that is primarily directed towards milk production by cows from own breeding. In so far as the farmer judges a change of the stock size desirable, he chooses in every period from among the heifer calves, that are born in that period out of this herd, a number for the purpose of breeding. All other heifer calves and all the bull calves he sells for fattening to other specialized farms. As soon as the selected calves have reached the age when they can reproduce, they are put in calf, if they still meet the selection requirements, and sold for slaughter if they do not. After completing the gestation period of nine months as heifer in calf, these animals enter the farm's dairy herd as cow. After four to five lactation periods (and calves) they are finally sold for slaughter, because they are no longer sufficiently productive. For reasons of consistent aggregation the farmer is neither allowed to buy breeding-cattle from other dairy farms nor to sell it to other dairy farms.

Now, every year again, the farmer faces the same problem. How many of the heifer calves born should be retained at the farm for breeding, how many heifers should be sold for slaughter or put in calf and finally how many cows should be culled. As soon as he has reached this decision, the development of the live stock in that period is known, given the opening stock and ignoring loss by death. We assume that the dairy farmer must take such decisions for  $T$  consecutive years. At the end of year  $T$  he sells



his live stock to a new owner. Because revenues and expenses are distributed over the life time of the animals, this decision problem is really an investment problem.

In deciding upon these questions it holds that the possibilities in a particular period are partly dependent on decisions taken in the past, just as this period's decisions (co)determine the farm's future herd development. It also holds that the farmer in determining the size and age composition of the stock must take into account the capacities of labor, dead stock and funds he has at his disposal. His decisions must always fit within the framework given by these factors. In this paper however we will neither pay attention to the coherence and interaction between these factors and the live stock nor to the possibility and consequences of extending the capacities of these factors. For simplicity's sake we confine ourselves to the live stock. Extensions are dealt with in [4].

One can, on good grounds, hold the view that a farmer, in choosing from a set of alternatives, is satisfied, as soon as he reaches his aspiration level. Here, however, we will not proceed from a satisfying, but from a maximising concept. The objective used here is maximization of the value of (discounted) cash-flows, generated by the farmer's decisions. This criterion, though one-sided, without doubt forms an important element in comparing alternatives, directly related as it is to the consumption possibilities of these production/consumption households. Of course, in such an approach leisure has no value.

### 3. The model

We assume that the lactation and dry period together make up a year, so every cow in calf gives birth to one calf a year, with equal probability a heifer or a bull calf. During the year following on that in which a heifer calf is born, it enters the heifer (or yearling) category. Heifers can be put in calf (inseminated) or sold for slaughter, either in the year of entering the heifer category or later on. We suppose that between the moment of a heifer's insemination and its calving lies a period of a year, too.

Let  $vk_t$ ,  $p_t$ ,  $v_t$ ,  $c_t$ ,  $t = 0, 1, \dots, T$  denote the number of respectively heifer calves, heifers, heifers in calf and lactating cows at the farm at

time  $t$ ,  $vk_t$ ,  $vp_t$ ,  $vc_t$  the number of heifer calves, heifers and cows, sold for slaughter in year  $t$ , and  $d_t$  the number of heifers put in calf in year  $t$ . The development of the farm's herd can now be represented by the following equations:

$$\begin{aligned}
 vk_t &= \frac{1}{2} (v_{t-1} + c_{t-1}) - vk_t \\
 p_t &= vk_{t-1} + p_{t-1} - vp_t - d_t \\
 v_t &= d_t \\
 c_t &= v_{t-1} + c_{t-1} - vc_t
 \end{aligned}
 \quad t = 1, \dots, T \quad (3.1)$$

In matrix notation this reads

$$Y_t = C_1 Y_{t-1} + C_2 X_t, \quad (3.2)$$

where

$$Y'_t = [vk_t, p_t, v_t, c_t], \quad X'_t = [vk_t, vp_t, d_t, vc_t],$$

$$C_1 = \begin{bmatrix} 0 & 0 & \frac{1}{2} & \frac{1}{2} \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{bmatrix} \quad C_2 = \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & -1 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix}$$

As remarked above transactions in breeding-cattle between dairy farms will be left out of consideration, because such transactions have no influence on the investment level of the sector as a whole. In view of that the vector of decision variables,  $X_t$ , is required to be non-negative. Also, no more heifer calves, heifers or cows can be sold for slaughter (or inseminated) than available. Supposing that  $X_t$  never reaches its minimum or maximum, we can leave out of consideration the related restrictions. As a consequence, the decision problem to be formulated at the end of this section is sizably simplified.

Also, the opening stock being positive,

$$Y_0 = \bar{Y}_0 (> 0), \quad (3.3)$$

the vector  $Y_t$  will always be positive.

In deciding upon the size and age structure of the live stock the farmer is, as stated, guided by the objective of maximizing the value of discounted cash flows evoked by his decisions.

Revenues accrue to the farm from the delivery of milk to the dairy industry, the sale of heifer and bull calves, and the sale of heifers and culled cows for slaughter.

The level of milk production by the dairy herd depends on many factors. Important in the long term analysis here are breed, age composition and genetic potential of the average cow. Keeping breed constant we suppose that the revenues from milk in year  $t$  are

$$pm_t(1+g)^t \{a_1 c_{t-1} + a_3 v_{t-1} - a_5 v c_t\}, \quad (3.4)$$

where  $pm_t$  denotes the price of milk in year  $t$ ,  $g$  the genetic improvement in percent a year and  $a_1, a_3, a_5$  the milk yield per dairy cattle category (for culled cows  $a_1 - a_5$ ).

Revenues from the sale of cattle amount to

$$pk_t \left\{ \frac{1}{2} (c_{t-1} + v_{t-1}) + v v k_t \right\} + pp_t \cdot v p_t + pc_t \cdot v c_t, \quad (3.5)$$

where  $pk_t$ ,  $pp_t$  and  $pc_t$  denote the price of a calf, a heifer and a culled cow respectively. We suppose that these prices are independent of the numbers sold.

In a more complete representation the revenues side also comprises cash receipts from borrowing, but, as remarked before, the aspect of financing the investment/production activities by own or borrowed funds will not be considered here.

Expenditures are done for the acquisition of dead stock, the payment of interest and redemption of debt and for buying concentrates, fertiliser, fuel etc. In this paper, however, we confine ourselves to those expenses which can without allocation be attributed to the live stock, e.g. concentrates. We will specify these expenses as a quadratic function of the distinct cattle categories. Having a linear revenues function we



achieve in such a manner that there exists an optimal size of the live stock. The parameters of this expenditures function reflect the prices of the inputs, such as fodder bought, and the state of technology. We assume, that all of these coefficients change conform inflation during the planning period.

Within the expenses evoked by the live stock we discern on the one hand expenditures determined by the size of a cattle category and on the other hand expenditures determined by the age composition of a category. Leaving inflation a moment aside the size dependent expenditures comprise the following four components, one for each cattle category,

$$\begin{aligned}
 \frac{1}{2} b_1 v k_t^2 &= \frac{1}{2} b_1 \left( \frac{1}{2} v_{t-1} + \frac{1}{2} c_{t-1} - v v k_t \right)^2 \\
 \frac{1}{2} b_2 p_t^2 &= \frac{1}{2} b_2 (p_{t-1} + v k_{t-1} - v p_t - d_t)^2 \\
 \frac{1}{2} b_3 v_t^2 &= \frac{1}{2} b_3 d_t^2 \\
 \frac{1}{2} b_4 c_t^2 &= \frac{1}{2} b_4 (v_{t-1} + c_{t-1} - v c_t)^2
 \end{aligned} \tag{3.6}$$

On top of these come the age dependent expenditures which arise when the animals within a category on average become older or younger,

$$\begin{aligned}
 \frac{1}{2} b_5 (p_{t-1} - v p_t - d_t)^2 \\
 \frac{1}{2} b_6 (c_{t-1} - v c_t)^2
 \end{aligned} \tag{3.7}$$

If  $p_{t-1}$  is equal to  $v p_t + d_t$ , the breeding expenses for heifers in that period amount to  $\frac{1}{2} b_2 v k_{t-1}^2$ . If, however  $v p_t$  and  $d_t$  are both equal to 0, then these expenses total  $\frac{1}{2} b_2 (p_{t-1} + v k_{t-1})^2 + \frac{1}{2} b_5 p_{t-1}^2$ .

The sum of the expenditures components (3.6) and (3.7) will be denoted by the symbol  $TE_t$ .

The net returns to the farmer in guilders of constant purchasing power can now be summarized by the following expression:

$$NR_t = \left\{ \prod_{j=1}^t (1+i_j) \right\}^{-1} \{P'_{y,t} Y_{t-1} + P'_{x,t} X_t\} - \frac{1}{2} [Y'_{t-1} X'_t] \begin{bmatrix} A_1 & A_2 \\ A'_2 & A_4 \end{bmatrix} \begin{bmatrix} Y_{t-1} \\ X_t \end{bmatrix},$$

$$t = 1, \dots, T \quad (3.8)$$

where  $i_j$  denotes the inflation percentage in year  $j$ ,

$$P'_{y,t} = [0, 0, \frac{1}{2} pk_t + pm_t(1+g)^t a_3, \frac{1}{2} pk_t + pm_t(1+g)^t a_1]$$

$$P'_{x,t} = [pk_t, pp_t, 0, pc_t - pm_t(1+g)^t a_5]$$

and

$$A_1 = \frac{\partial^2 TE_t}{\partial Y_{t-1}^2}, \quad A_2 = \frac{\partial^2 TE_t}{\partial Y_{t-1} \partial X_t}, \quad A_4 = \frac{\partial^2 TE_t}{\partial X_t^2}$$

For year  $T$ , the sale of the stock comes on top of the revenues in that year.

Now that a specification of net returns is available, the decision problem the farmer faces in the first year within the planning horizon can be represented by the following model, compare also [1] and [3],

$$\max F = \sum_{t=1}^T \beta^t \left\{ \prod_{j=1}^t (1 + {}_1i_j^E) \right\}^{-1} \{ {}_1P'_{y,t} Y_{t-1} + {}_1P'_{x,t} X_t \} +$$

$$- \frac{1}{2} [Y'_{t-1} X'_t] \begin{bmatrix} A_1 & A_2 \\ A'_2 & A_4 \end{bmatrix} \begin{bmatrix} Y_{t-1} \\ X_t \end{bmatrix} + \beta^T \left\{ \prod_{j=1}^T (1 + {}_1i_j^E) \right\}^{-1} \{ {}_1P'_{y,T+1} Y_T \} \quad (3.9)$$

subject to

$$Y_t = C_1 Y_{t-1} + C_2 X_t$$

$$Y_0 = \bar{Y}_0$$

Here  $\beta$  denotes the discount factor the farmer uses and  ${}_1i_j^E$  the inflation percentage that he in year 1 expects to be valid for year  $j$ . The vectors  ${}_1P'_{y,t}$  and  ${}_1P'_{x,t}$  specify his expectations in year 1 with respect to the returns from milk delivery and cattle sales in year  $t$ ,

$${}_1P_{y,t}^E = [0, 0, \frac{1}{2} \cdot {}_1pk_t^E + {}_1pm_t^E(1+g)^t a_3, \frac{1}{2} \cdot {}_1pk_t^E + {}_1pm_t^E(1+g)^t a_1]$$

$${}_1P_{x,t}^E = [{}_1pk_t^E, {}_1pp_t^E, 0, {}_1pc_t^E - {}_1pm_t^E(1+g)^t a_5]$$

Finally, the vector  ${}_1P_{y,T+1}^E = [{}_1pk_{T+1}^E, {}_1pp_{T+1}^E, \frac{1}{2}({}_1pp_{T+1}^E + {}_1pc_{T+1}^E), {}_1pc_{T+1}^E]$  denotes the prices the farmer expects to receive from selling his live stock to a new owner at the end of the planning horizon. The expected prices for the first year are, of course, equal to the actual prices in that year, i.e.  ${}_1i_1 = i_1$ ,  ${}_1P_{y,1}^E = P_{y,1}$  and  ${}_1P_{x,1}^E = P_{x,1}$ .

#### 4. The solution

The decision problem (3.9) (and those for the following years which possess the same structure) can be solved in several ways, e.g. recursively. Now for some as yet unknown reason it holds, that

$$(C_1 - C_2 A_4^{-1} A_2')^2 = 0 \quad (4.1)$$

and

$$(C_1 - C_2 A_4^{-1} A_2')'(A_1 - A_2 A_4^{-1} A_2') = 0 \quad (4.2)$$

Using these features we can obtain the optimal solution in a simple way. This solution is

$$X_t = -A_4^{-1} A_2' Y_{t-1} + Q_t^{-1} W_t, \quad t = 1, \dots, T-2 \quad (4.3)$$

where

$$Q_t = A_4 + \beta C_2'(A_1 - A_2 A_4^{-1} A_2')C_2, \quad (4.4)$$

$$W_t = \left\{ \prod_{j=1}^t (1+i_j) \right\}^{-1} \{P_{x,t} + (1 + t^i E_{t+1})^{-1} \beta C_2'({}_tP_{y,t+1}^E - A_2 A_4^{-1} {}_tP_{x,t+1}^E) + \\ + \{(1 + t^i E_{t+1})(1 + t^i E_{t+2})\}^{-1} \beta^2 C_2'(C_1' - A_2 A_4^{-1} C_2')({}_tP_{y,t+2}^E - A_2 A_4^{-1} {}_tP_{x,t+2}^E)\} \quad (4.5)$$

For space considerations the slightly different expressions for  $T-1$  and  $T$  are omitted. For the same reason we will not write down the whole solution in extenso. Instead we present the decision rules in which we are interested here: the investments,  $d_t$ , and the desinvestments,  $vc_t$ .

For the simple model considered here the optimal level of the inflow of heifers in calf in the dairy stock is given by the following expression, obtained by using a formula manipulation language,

$$\begin{aligned}
 d_t = & - \frac{b_4 + b_6}{n_3} p p_t + \frac{\beta(b_4 + b_6)}{(1 + {}^E_{t,t+1})n_3} t^{pk}_{t+1} + \frac{\beta(1+g)^{t+1}\{b_4(a_3 - a_5) + b_6 a_3\}}{(1 + {}^E_{t,t+1})n_3} t^{pm}_{t+1} + \\
 & + \frac{\beta b_4}{(1 + {}^E_{t,t+1})n_3} t^{pc}_{t+1} + \frac{\beta^2 b_6}{(1 + {}^E_{t,t+1})(1 + {}^E_{t,t+2})n_3} t^{pk}_{t+2} + \\
 & + \frac{\beta^2(1+g)^{t+2}b_6(a_1 - a_5)}{(1 + {}^E_{t,t+1})(1 + {}^E_{t,t+2})n_3} t^{pm}_{t+2} + \frac{\beta^2 b_6}{(1 + {}^E_{t,t+1})(1 + {}^E_{t,t+2})n_3} t^{pc}_{t+2}, \quad (4.6)
 \end{aligned}$$

$$\text{where } n_3 = \prod_{j=1}^t (1 + i_j) (2\beta b_4 b_6 + b_4 b_3 + b_6 b_3).$$

For the optimal culling level we find

$$\begin{aligned}
 vc_t = & \frac{b_4}{n_4} v_{t-1} + c_{t-1} - \frac{(1+g)^t a_5}{\prod_{j=1}^t (1 + i_j) n_4} p m_t + \frac{1}{\prod_{j=1}^t (1 + i_j) n_4} p c_t + \\
 & - \frac{\beta}{\prod_{j=1}^t (1 + i_j) (1 + {}^E_{t,t+1}) n_4} t^{pk}_{t+1} - \frac{\beta(1+g)^{t+1}(a_1 - a_5)}{\prod_{j=1}^t (1 + i_j) (1 + {}^E_{t,t+1}) n_4} t^{pm}_{t+1} + \\
 & - \frac{\beta}{\prod_{j=1}^t (1 + i_j) (1 + {}^E_{t,t+1}) n_4} t^{pc}_{t+1}, \quad (4.7)
 \end{aligned}$$

$$\text{where } n_4 = b_4 + b_6.$$



If  $c_{t-1}$  in (4.7) is brought from the right to the left hand side and  $c_{t-1}^{-vc_t}$  is substituted by  $c_t^{-v_{t-1}}$ , (4.7) becomes

$$\begin{aligned}
 c_t = & \frac{b_6}{n_4} v_{t-1} + \frac{(1+g)^t a_5}{t \prod_{j=1} (1+i_j) n_4} p m_t - \frac{1}{t \prod_{j=1} (1+i_j) n_4} p c_t + \\
 & + \frac{\beta}{t \prod_{j=1} (1+i_j) (1+t^E_{t+1}) n_4} t^{pk^E_{t+1}} + \frac{\beta(1+g)^{t+1} (a_1 - a_5)}{t \prod_{j=1} (1+i_j) (1+t^E_{t+1}) n_4} t^{pm^E_{t+1}} + \\
 & + \frac{\beta}{t \prod_{j=1} (1+i_j) (1+t^E_{t+1}) n_4} t^{pc^E_{t+1}} \quad (4.8)
 \end{aligned}$$

The investments in year  $t$  are according to (4.6) determined by the (de-flated) actual and expected prices. The desinvestments in year  $t$ , (4.7), also depend on the size of the dairy herd at time  $t-1$  and the inflow in period  $t-1$ . The weight of each factor depends on coefficients from the revenues and expenditures functions. Curious about (4.6) and (4.7) and the other equations in (4.3) is that its variables only refer to the current and the future two years. One would rather expect the prices of all future periods to play a role. It must be admitted that these rules are hardly interpretable in economic terms. Of course, on the basis of the derivation followed, it can not be misunderstood that the equality of marginal revenues and costs hides behind these expressions, but it is not clear how to state this in economic terms.

In (4.6) and (4.7) the factors are identified which determine the (optimal) level of the (des)investment in the dairy stock and also the specific influence of each of these variables. By means of these relations one can assess to what extent the stock size (and so cet.par. the level of the milk supply) reacts on changes in the price for milk.

The average size of the dairy cow stock in period  $t$  amounts to

$$\bar{c}_t = \frac{c_{t-1} + c_t}{2} \quad (4.9)$$

The insertion of (4.8) in (4.9) gives this average as a function of amongst others the prices and price expectations in that period. In view of the dependence of  $c_{t+1}$  on  $v_t$  these prices also influence  $\bar{c}_{t+1}$  and  $\bar{c}_{t+2}$ . Under the assumption that the milk price expectations in (4.6) and (4.8) only depend on  $pm_t$ , as far as it concerns milk prices, the effect of a change in the milk price in period  $t$  on the average size of the dairy cow stock is expressed by

$$\frac{\partial c_t}{\partial pm_t} + \frac{\partial c_t}{\partial v_t} \frac{\partial pm_{t+1}^E}{\partial pm_t} + \frac{\partial c_{t+1}}{\partial v_t} \left[ \frac{\partial v_t}{\partial pm_{t+1}^E} \frac{\partial pm_{t+1}^E}{\partial pm_t} + \frac{\partial v_t}{\partial pm_{t+2}^E} \frac{\partial pm_{t+2}^E}{\partial pm_t} \right], \quad (4.10)$$

or, shortly, by

$$\frac{\partial c_t}{\partial pm_t} + \frac{\partial c_{t+1}}{\partial v_t} \frac{\partial v_t}{\partial pm_t} \quad (4.11)$$

Under the assumption just mentioned the long run elasticity,  $\frac{\Delta \bar{c}}{\Delta pm} \frac{pm}{\bar{c}}$ , can be determined by for instance the average of the elasticities in the several years.

$$\frac{\Delta \bar{c}}{\Delta pm} \frac{pm}{\bar{c}} = \frac{1}{T} \sum_{t=1}^T \left[ \left( \frac{\partial c_t}{\partial pm_t} + \frac{\partial c_{t+1}}{\partial v_t} \cdot \frac{\partial v_t}{\partial pm_t} \right) \frac{pm_t}{\bar{c}_t} \right] \quad (4.12)$$

The elements  $\frac{\partial c_t}{\partial pm_t}$ ,  $\frac{\partial c_{t+1}}{\partial v_t}$  and  $\frac{\partial v_t}{\partial pm_t}$  can be obtained by means of the estimates for the corresponding regression coefficients. Should the milk price expectations in (4.6) and (4.8) also depend on other milk prices than the one of period  $t$ , then (4.10) has to be adjusted accordingly.

The reaction equations (4.6) and (4.8) are derived at micro level, so the elasticity (4.12) can be estimated using data concerning individual farms. However, if we assume that the same type of model as the one derived holds for all firms in the sector, the conditions for consistent aggregation are satisfied and estimation of (4.12) using data with respect to the sector as a whole is also allowed [4].

## 5. Conclusion

We have shown above how from a model for the long term development of milk supply decision rules for the (des)investments in the dairy cow stock can be derived. Such rules supply a starting point for e.g. a statistical investigation into the long run reaction of the milk production to the milk price. More realistic rules result when dead stock and debt financing are incorporated.

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